25. *On a* Case *of* Unconformity *and* Thrust *in the* Coal-Measures *of* Northumberland.

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[Plate XLII—Section.]

I. Introduction.

The object of this paper is to describe a case of unconformity, accompanied by a certain amount of horizontal thrusting, which occurs in the Coal-Measures exposed—chiefly at low water—on the coast of Northumberland at the foot of the Whitley cliffs, and is traceable for upwards of a mile.

The section studied stretches from the bold headland formed by the Table Rocks,[1] northwards almost as far as the Brier-Dene Burn. At the southernmost end—that is, at the Table Rocks—the plane of erosion in question dips and disappears beneath the sea. Near the mouth of Brier Dene it is permanently covered and concealed by Drift and beach-deposits.

The Table Rocks consist of a series of ledges of sandstone, bedded almost horizontally, and presenting vertical cliff-faces to the sea. A little north of this the cliff becomes overhanging, owing to the undercutting by the waves of the soft beds which come to light at its base.

Near the spot marked M on the sketch-map (fig. 1, p. 532), the sandstone-cliff, which so far varies from 30 to 40 feet, gradually lessens in height, and is overlain by a considerable thickness of Boulder-Clay. Up to this point also the foreshore is free from cover, though strewn with boulders, and in places obscured by talus-heaps burying the cliff-foot, and the strata comprised in it can be well seen at low tide. Farther north, however, the boulder-strewn outcrops give place to a broad sandy beach (Whitley Sands proper), which is broken, near low-water-mark only, by a reef of sandstone. But, after specially-heavy storms, the shifting sands, at rare intervals of time, bring into view sometimes shingle, and sometimes solid rock. It was after such a storm that an unusually-fine exposure of the unconformity was observed and recorded by one of us more than twenty years ago.[2] It is only by watching the coast, and seizing favourable opportunities during many years, that most of the details here given have been obtained.

The uppermost deposit along this portion of the coast is the yellow sandstone which forms the Table Rocks, and we shall call it by that name. About 40 feet of this well-marked rock is visible in the cliffs of which it is the main constituent, and its total thickness, as shown in sinkings inland, is not more than 50 feet. It is more massive and compact in the southern parts of the section, thin and irregular subordinate layers of shale developing within it farther north. Its base lies unconformably upon a series of alternating shales and sandstones, and it is this unconformable junction which we propose to describe.

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[1] This name, although always used in the locality, has not, unfortunately, been adopted by the Ordnance Survey.

[2] See 'Nature' vol. xxv (1881) p. 79 (November 24th).

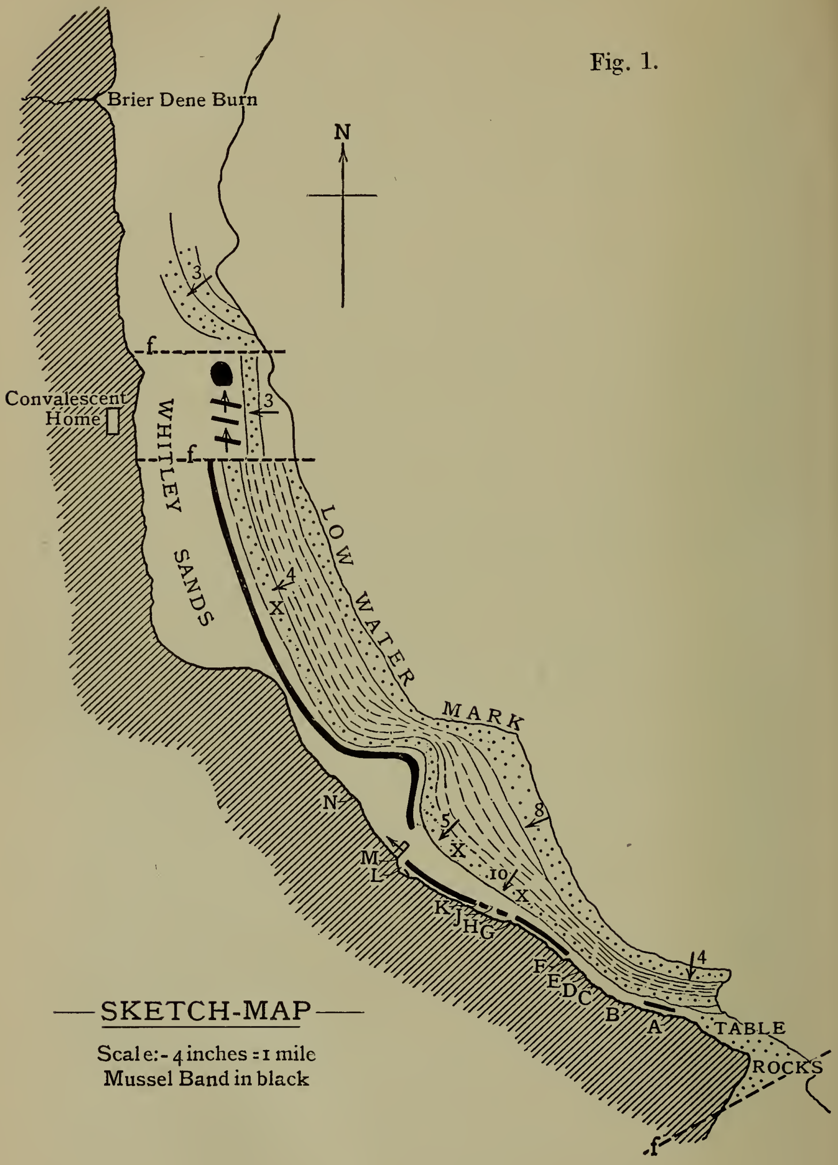
From beneath the line of unconformity to the lowest tide-level, about 30 to 40 feet of the shales and sandstones just mentioned can be observed and measured; but only the topmost 8 or 10 feet of this series can be proved to have been subjected to the denudation which preceded the deposition of the Table-Rocks Sandstone, although it is natural to suppose that considerably more was involved in an erosion so widespread as this. How much missing rock the unconformity may represent it is not possible, with the evidence at present available, to tell.

The dip of both sets of beds—above and below the unconformity—is, except where in the lower these are faulted and disturbed, one of a few degrees (about 4° on the whole) to the south-west, or inland. This brings about a general parallelism between the scarped outcrops of the cliff-making Table-Rocks Sandstone and the hard bands of sandstone of the lower series, which has, no doubt, helped for many years to mask, and withdraw attention from, the unconformity.

Since beds of shale and sandstone (such as those of the lower series) are of the kind which is common in all parts of the Coal-Measures in this coalfield, and bear no special characters by which they could be distinguished, it is fortunate that the series includes in its upper portion a stratum of marked individuality—a bed of clay-ironstone crowded with shells of *Carbonicola* (olim *Anthracosia*) *aquilina*, which we will call the Mussel-Band, a bed which serves as a most useful and unmistakable horizon of reference.

It may be permissible to remind the reader that in the Upper Carboniferous of the North of England, mussel-bands are, with the possible exception of the thicker coal-seams only, quite the most persistent strata met with. In consequence of their remarkable constancy, they are of great use as guiding-beds in seeking for, and in correlating, certain coals. If the correlation adopted in the Geological Survey-map of this district be followed, then this particular shelly ironstone is one well-known as occurring a little way above the Low Main Seam, but this reference we are not at present in a position either to combat or to confirm. Indeed, the recognition of the unconformity throws many difficulties in the way of the correct interpretation of inland pit- and bore-sections, and doubt must (for a time at least) exist as regards several of them.

Fig. 1.



SKETCH-MAP

Scale:- 4 inches = 1 mile
Mussel Band in black

The beds referred to in this paper are the following :—

	Feet.
UPPER SERIES.	
The 'Table-Rocks' Sandstone	30+
Unconformity.	
LOWER SERIES.	
Shales	12+
Mussel-Band	about 1
Shale	3
Sandstone	8
Shale	8
Sandstone	10 to 12
Shales, etc.	—

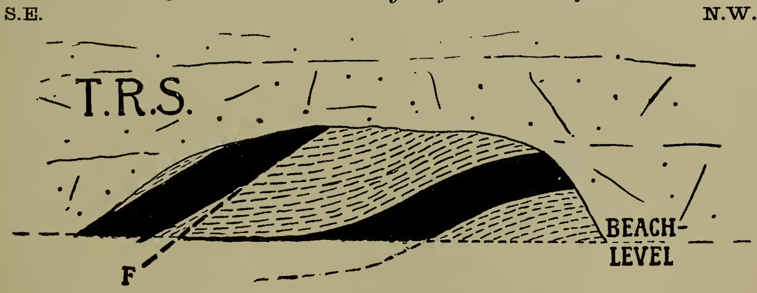
II. DESCRIPTION OF THE PHENOMENA.

We will now briefly describe the more noteworthy facts observable in following the unconformity from south to north, taking each point as it comes.

From A (see sketch-map, fig. 1, p. 532), where the junction of the two series emerges from the sea, to B, there is no discordance of dip, and no disturbance in either: nothing, in fact, to draw the attention to any break in the succession. A thin shale, merely, separates the Mussel-Band from the Table-Rocks Sandstone. The actual junction is buried under shore-deposits.

At B, the base of the Upper (Table-Rocks) Sandstone is suddenly raised to accommodate a small faulted and denuded portion of lower beds. This disturbed space, 6 to 7 feet in length, includes a high dip of the Mussel-Band and a reversed fault of small throw, hading to the south-east, as shown in fig. 2, below.

Fig. 2.—*Section B; length of section = 6 feet.*



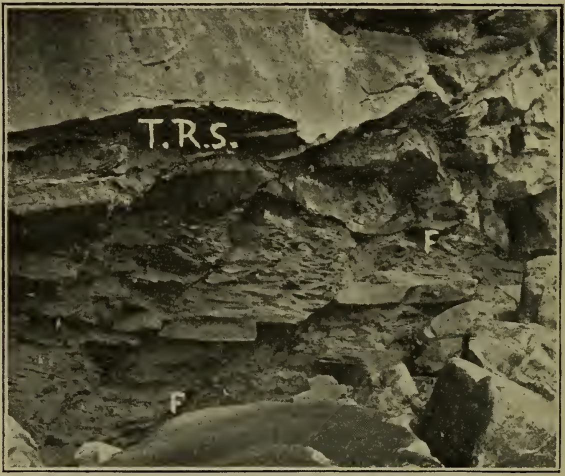
[The vertical scale is the same as the horizontal.]

T.R.S. = Table-Rocks Sandstone; the Mussel-Band is shown in black.

A few yards farther on, the line of unconformity again rises above the beach-level, and another and longer islet of shale (beneath the horizon of the Mussel-Band) is well shown. The junction here is of especial interest, as the Table-Rocks Sandstone at its very base is seen to contain pebbles of material belonging to the Lower Series. These pebbles will be referred to more fully, later. The shales beneath the unconformity are discordant as to dip from the sandstone above, but not otherwise disturbed or faulted.

For the next 40 yards the junction is again hidden beneath the boulder-covered beach, until at C another good exposure is obtained. Pebbles are once more present. The dips are very discordant, and towards its northern end the lower set of beds is disturbed by faults of great hade. (See fig. 3, below.)

Fig. 3.—*Photograph showing the fault in the Lower Series stopping short at the base of the Table-Rocks Sandstone.*

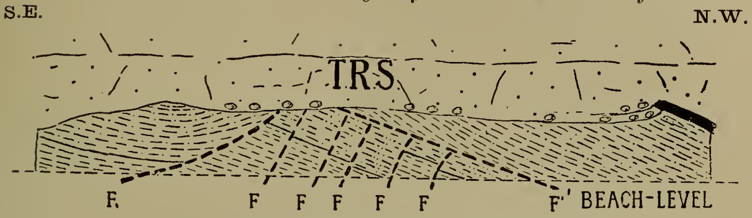


Some 25 to 30 yards of stony talus intervenes between this and the next fine exposure, from D to E. Here the discordance is very marked, the lower beds exhibiting synclinal and anticlinal folds, on the denuded edges of which the Table-Rocks Sandstone lies nearly flat, with some pebbles (not only, this time, at its immediate base, but, towards the northern end of the section, also a foot or two higher up). A notable feature here, is the way in which the central portion is shattered by a number of small faults, about half of which are reversed. All the smaller faults hade to the south, and are fractures subordinate to a larger fault hading to the north at an angle of about 45°. At E the bottom-layers of the Table-Rocks Sandstone are somewhat violently upturned, as if on meeting the resistance presented by the hard Mussel-Band, which here reappears abutting against the line of junction, and dipping at a fairly high angle to the north. (See figs. 4 & 5, p. 535.)

About 20 yards farther north, a perfectly-concordant junction is seen for a short distance, with horizontal shale beneath the equallyhorizontal Table-Rocks Sandstone, at the base of which pebbles again occur.

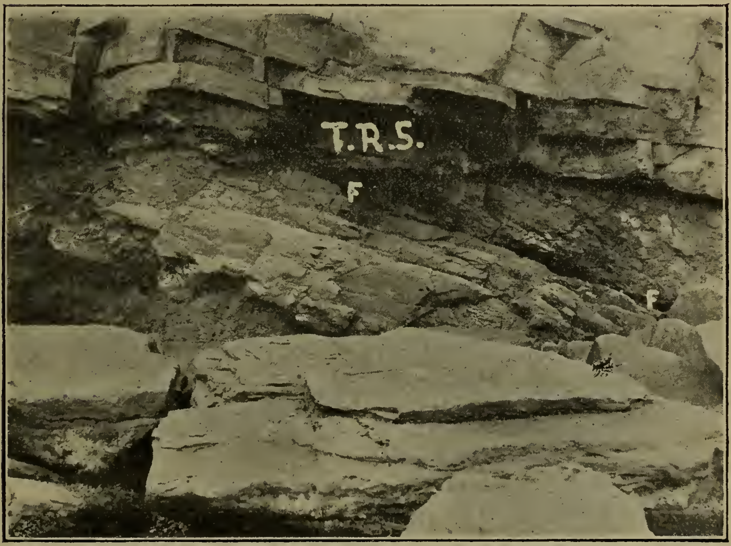
Another 25 yards of unseen talus-covered junction brings us to what is one of the most violently-disrupted episodes (F) in the entire cliff-section. Nothing but a diagram and photographs can render this intelligible. (See figs. 6 & 7, p. 536.)

Fig. 4.—*Section D to E; length of section = about 100 feet.*



[The vertical scale is the same as the horizontal.]

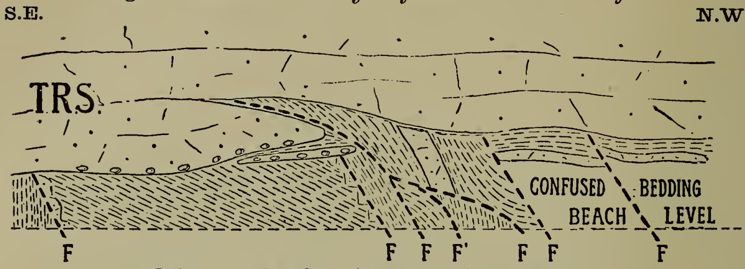
Fig. 5.—*Photograph illustrating fig. 4. (See also p. 534.)*



[FF is the fault F′ of fig. 4, hading northward.]

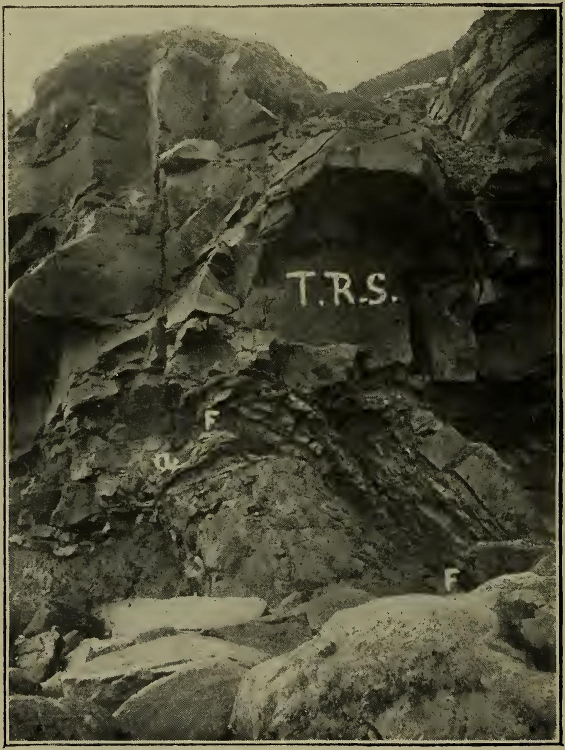
Especially noteworthy here, is the manner in which the lowest layer of the Upper-Sandstone Series seems to have wedged itself plough-like into the superficial portion of the lower denuded beds, and in so doing has bent up the harder bands in the latter to an angle approaching the vertical. The broken masses of sandstone included in the Lower Series near the line of the unconformity at

Fig. 6.—*Section F; length of section = about 80 feet.*



[The vertical scale is the same as the horizontal.]

Fig. 7.—*Photograph illustrating fig. 6.*



the northern end of the section, seem due to the same order of phenomena; and the whole testifies to movement of the great cliff-sandstone over the edges of the Lower Series in a northerly direction.

Though at first sight strongly suggestive of ordinary faulting, this particular section, on being carefully studied, is, we believe, more reasonably explained by the effects of local irregularities as obstacles in the progress of a horizontal thrust. Pebbles are here again found at the actual base, as well as a little above it in the sandstone. In this, and in some of the highly-disturbed and faulted sections, the whole is so crushed and broken, that it is impossible in places to recognize any prevailing dip.

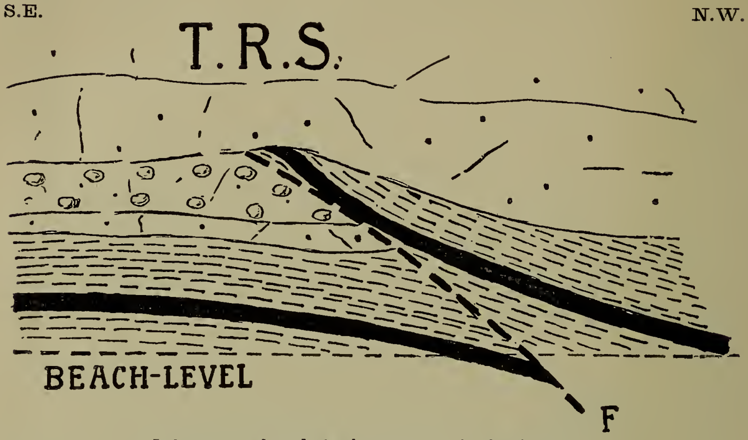
A few yards north of F a long extent of cliff is reached, in which, except at two narrow spots, the actual unconformity is covered by talus-material; but the Mussel-Band crops out on the beach a few yards from the cliff, and its perfect regularity and parallelism with the Upper Sandstone show that no trace of the disturbance at F is left, and that there can be scarcely any discordance of dip. Indeed, the two small exposures just mentioned prove this to be the case. Pebbles are there seen about a foot above the base of the Table-Rocks Sandstone.

On approaching G the Mussel-Band dips gently northward, to be soon thrown up again by a reversed fault hading in the same direction, so as to abut under the unconformable sandstone, whence it again dips northward at the same angle as before (see fig. 8, p. 538). In this section the pebbles, which are numerous, are only seen on the southern side of the fault which causes the Mussel-Band to override the conglomerate formed by them ; consequently, here the Mussel-Band actually overlies a bank of pebbles derived from itself.

At H the same northerly dip (with absence of pebbles at the unconformity) is observable. Here are two small faults affecting the lower beds, but, of course, stopping short beneath the Upper Sandstone (see fig. 9, p. 538).

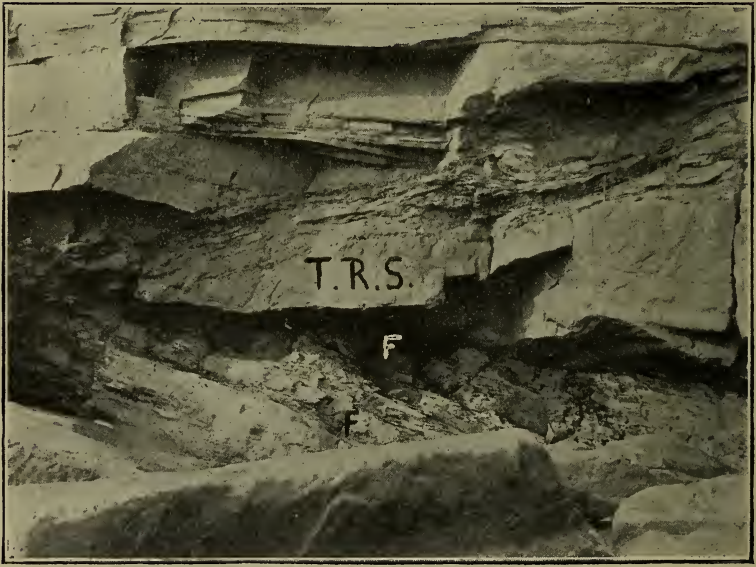
Many yards of obscuring talus follow, to be succeeded by a long exposure of perfectly-horizontal Table-Rocks Sandstone, beneath which the lower shales dip at a regular angle of about 15° to the north. Only a few pebbles are to be seen above the junction along this stretch of cliff. This arrangement continues to J. Here is one of the transverse stony ridges to be referred to later on (see p. 546 & fig. 10, p. 539). This little ridge is followed by highly-dipping shaly beds until the Mussel-Band is reached. The latter exhibits a thrust-like disturbance, being sundered by a fracture which causes its southern edge to rear and overtop slightly the northern. Here, as elsewhere, the direction of the movement must obviously have been from south to north. A fault at this place restores the Lower Series of beds to horizontality, with the Mussel-Band running parallel to the Upper Sandstone as before. At K, however, the Lower Series dips sharply to a fault. This fault has little effect, as on its upthrow side the Mussel-Band is once more a few feet beneath the plane of the unconformity, and continues regular, with a slight dip inland, for some 200 yards farther until L is reached. Consideration of a second stony ridge which occurs at K is deferred until later (see *postea*, p. 548).

Fig. 8.—*Section G; length of section = about 15 feet.* (*See p. 537.*)



[The vertical scale is the same as the horizontal.]

Fig. 9.—*Photograph showing the discordance of dip between the Upper and the Lower Series.* (*See p. 537.*)

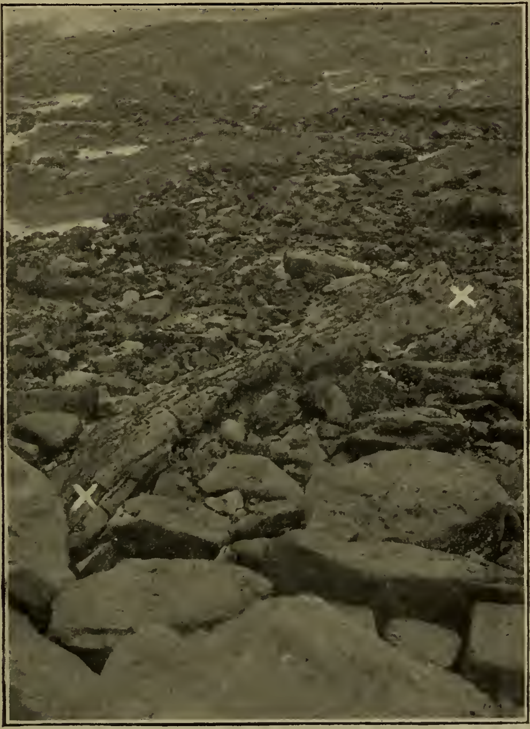


[FF is a small fault which affects the Lower Series only.]

At L a beautiful little overfold is exhibited in the Mussel-Band and accompanying shales. In the little bay hard by, an interesting reduplication of the Mussel-Band, due to a north-and-south fault, has quite recently been exposed (November 15th, 1905), as shown in the accompanying sketch-plan (see fig. 11, p. 540).

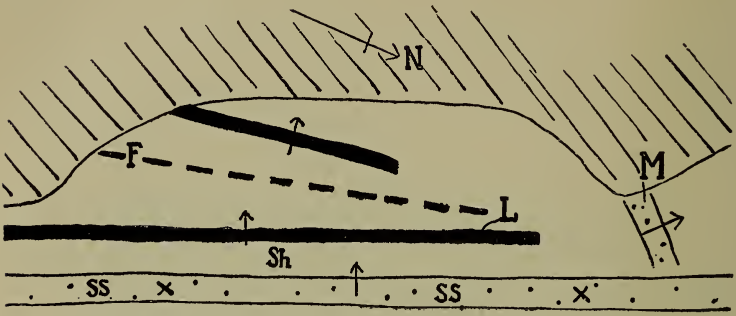
At the northern end (M) of this bay are several parallel stony ridges similar to those described farther on (p. 546). From this point onwards to N, the cliff-section presents a number of complications, which, while they emphasize the evidence in favour of a thrusting movement from south to north, at the same time render it difficult to follow clearly the line of unconformity. The accompanying diagram (Pl. XLII) will show the main features of the case better than a detailed description. The difficulty is partly due to the fact that from M northward, the lower course of the Table-Rocks Sandstone loses much of its continuously-massive character, being partly replaced by shale in which tongues of sandstone from the higher portions of the deposit are here and there intercalated, as well as isolated lenticular patches of sandstone. Much of this lower course is also concretionary. Pebbles are fairly plentiful, but appear as a rule to be limited to the bottom of these irregular

Fig. 10.—*Photograph showing the ridge on the foreshore at J.*



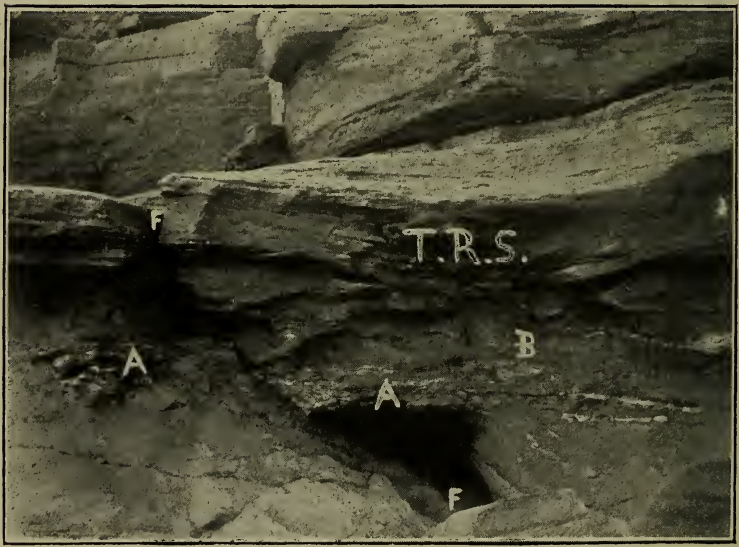
[The ridge is marked by two white crosses, and is seen to end abruptly seaward, that is, to the right of the photograph.]

Fig. 11.—*Sketch-plan showing the outcrop of the Mussel-Band in the bay near* L. *(See pp. 538–39.)*



[The Mussel-Band is shown in black; SS=Sandstone; Sh=Shale. The heavy broken line indicates a fault.]

Fig. 12.—*(See also Pl. XLII and p. 541.)*



[F F is a fault (FM^{1} in Pl. XLII) affecting not only the Lower Series, but also the bottom-course of the Table-Rocks Sandstone. A A is the pebble-bed, and the shales below this dip at a high angle northward. B is a rounded fragment of disturbed shale at the junction of the two series. The dark patch is a little cave weathered out along the fault.]

sandstone-layers. In the latter also occur numerous lenticular pockets of clean coal (locally known as 'scares'), and occasionally of shale. These 'scares' have a characteristic wavy outline, and, although not marked in the other sketches, abound at many places along the coast-section, occurring sometimes up to 6 feet above the base of the Table-Rocks Sandstone. At FM^{I}, and thence to FM^{II}, FM^{III}, FM^{IV}, FM^{V}, and FM^{VI}, are several faults; not, as before, in the series beneath the unconformity, but affecting the lower portions of the Upper Series only. Some of these are rectilinear with ordinary hades; but three (FM^{IV}, FM^{V}, and FM^{VI}) are curvilinear and very flat-haded. All, except the fault at FM^{I}, hade to the south. At N the section closes with a vertical fault which throws the whole of the rocks, both above and below the unconformity. In amount its throw is small, but the fault-fissure is well-marked and filled with clay or 'dowk' (fig. 12, p. 540).

It would seem as if the various appearances exhibited in this line of section may be explained by a certain amount of differential action within the beds above the unconformity, rendered possible only when these are, as in the present case, no longer homogeneous, but of rapidly-changing hardness and texture. Also perhaps in such circumstances a certain, though small, amount of intermingling of the Lower and Upper Series has taken place near the shearing-plane during the general thrusting movement towards the north.

Beyond N, the sandy beach rarely shifts sufficiently to afford many glimpses of the state of things beneath it, and but little information can be gleaned from the low Drift-covered cliffs. Opposite the Convalescent Home, however, some remarkable exposures are at times visible. These show a continuation of the kind of disturbance in the Lower Series of beds, which has been described as commonly occurring in them to the south of M. The Mussel-Band here again furnishes the best evidence at our disposal. Thus, between the water-pipe and the drain-pipe running from the Convalescent Home to the sea, the Mussel-Band is repeated three times by small east-and-west faults, and a little north of this, small anticlinals and isolated outcrops with curved strikes and dipping in various directions are observable, but the connexion between these stratigraphical details is necessarily wanting. There is no evidence whatever of the unconformity north of N.

It may be mentioned that, close to the low-water line immediately to the east of the small, though sharp, disturbances just noted, the strike of the thin sandstones below the Mussel-Band is normal in character, that is, parallel both to the coast-line and to the strike of the Table-Rocks Sandstone, which is here, however, only marked by a small surface-feature, and covered by Boulder-Clay and blown sand. This arrangement—faulted and folded beds west of, and close to, a continuous, unbroken north-and-south outcrop—suggests a strike-fault between the two areas. We have, however, failed to find any good evidence of such a fault, even a small one; and the recognition of the thrusting action renders such a fault unnecessary.

III. The Chemical Evidence.

The Pebbles in the Upper Series.—These have been described as occurring at many places—almost continuously indeed—at and near the base of the Table-Rocks Sandstone. At times, they form a narrow band immediately or a few inches above the unconformity; or again they are found sparsely scattered through a foot in thickness of the sandstone; or, finally, they occur in such numbers as to form a conglomerate many inches thick, as at G. Plant-remains, evidently drifted, and a few shells (*Carbonicola*) are also found, as well as angular and rounded pieces of shale and of the soft fossiliferous parts of the Mussel-Band; but well-rounded pebbles of the harder parts of the Mussel-Band far outnumber the rest of the included fragments of foreign material. The smaller of these well-rounded pebbles are sometimes much oxidized; the larger are slabs several inches thick and measuring up to a foot in diameter, with rounded edges, and containing the typical *Carbonicola*-shells irregularly distributed throughout the mass.

Comparative determinations of the constituents of these pebbles and of the mother-rock were made, with the following results:—

I and II are samples of collections of small pebbles found at F and G respectively.
III is a big pebble from E.
IV is from the Mussel-Band cropping out near G.
V is from the Mussel-Band cropping out near K.

In sampling the last two, the harder parts were selected, as the pebbles are mostly derived from these.

	I.	II.	III.	IV.	V.
Loss on ignition	28·43	28·30	30·74	32·71	32·81
Hygroscopic water	1·38	1·39	1·53	0·88	0·71
Combined water and organic matter ...	5·21	2·05	2·40	4·06	3·94
Insoluble in acids	11·51	12·78	9·12	8·16	7·06
Al_2O_3 (soluble in acids) ...	1·65	0·40	2·44	1·30	0·28
S	0·43	0·55	0·15	0·14	0·13
P_2O_5	0·39	0·29	1·49	0·75	1·01
MnO	0·92	0·97	1·29	1·56	1·35
FeO	35·62	36·90	39·11	32·24	40·93
Fe_2O_3	10·71	6·36	1·34	1·82	0·31
CaO	2·05	4·48	4·60	12·85	9·04
MgO	3·04	4·00	4·36	3·93	2·00
CO_2	25·80	28·96	31·15	31·35	32·71
Alkalies (by difference) ...	1·29	0·87	1·02	0·96	0·53
	100·00	100·00	100·00	100·00	100·00

The residue insoluble in hydrochloric acid from Sample III was found to contain 22·56 per cent. of carbonaceous matter and combined water. The ignited residue contained:—

SiO_2	61·01
Al_2O_3	28·05
Fe_2O_3	4·38
CaO	0·10
MgO	0·90
Na_2O	5·71
	100·15

Turning now to the detailed table of analyses, it will be seen that, while there is a general similarity in the composition of the various samples, Nos. I & II stand apart in some respect from the others, and the differences are such as might be expected to exist between small pebbles on the one hand, and large slabs and the mother-rock upon the other. Thus the insoluble matter is higher in the former case, due to mechanically-mixed sand; sulphur too is high, owing to the presence of pyritic nodules among the pebbles. The phosphorus-content of the small pebbles is lower than that of the Mussel-Band, from which it would appear that some leaching-out of the phosphates took place during weathering. In this connexion, it is noteworthy that the sandstone in which the pebbles are embedded is richer in phosphorus than the overlying pebble-free beds (see *postea*, p. 546). The small pebbles contain more ferric iron and less carbon-dioxide than the other samples, and this is in harmony with the normal weathering of a rock consisting largely of ferrous carbonate. Lime is variable, though on the whole higher in the large slab and the Mussel-Band. Since the lime is derived chiefly from the fossil shells, and since the presence of these makes the rock less able to withstand disrupting influences, it follows that the small pebbles will be mainly made up of the more homogeneous unfossiliferous portions of the rock. Magnesia is remarkably constant in all the samples. A similar phenomenon has been noted in the case of the Cleveland Ironstone, and has been held to be due to uniform dissemination of the magnesia in the form of glauconite.[1] An estimate of the amount of magnesia thus combined is readily obtained by calculating its equivalent to the shortage of carbon-dioxide; that is, the amount of carbon-dioxide still lacking when the acidic oxides have been all appropriated by the basic oxides. In the samples under discussion, it averages about 2 per cent.

It is clear, from the foregoing remarks, that the chemical evidence supports the view that the pebbles are derived from the Mussel-Band. This is brought out more strikingly by the following method of treatment:—

If the pebbles are more or less weathered portions of the Mussel-Band, which itself at its present outcrop is somewhat altered by weathering, then it should be possible, knowing the proximate composition of the rocks in question and the chemical changes which take place during weathering, to calculate the composition of the original rock from which both have been derived.

The only chemical change on weathering which need be considered in the present case, is the oxidation of ferrous carbonate to ferric oxide with loss of carbon-dioxide.

In order to determine the proximate composition of the rocks, we shall assume that the phosphoric oxide exists in combination with ferrous oxide as ferrous phosphate, and that the remainder of the ferrous oxide is present as carbonate; that the manganese is present as carbonate, since that body is not so easily oxidized as ferrous carbonate[1]; that the lime exists as carbonate, and also that portion of the magnesia for which there is still carbon-dioxide to combine with—the remainder of the magnesia we have already assumed to be present as glauconite. The following table gives the proximate composition of the samples (recalculated for the dry rock). Under the head of 'indifferent constituents' are included ferrous phosphate, combined water, organic matter, insoluble matter, alumina, sulphur, magnesia (present as glauconite), manganese-carbonate, and alkalies; that is, those bodies which would be practically unaltered by such gentle and partial oxidation as takes place during weathering.

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[1] R. Tate & J. F. Blake, 'The Yorkshire Lias' 1876, pp. 164 *et seqq.*

PROXIMATE COMPOSITION OF THE SAMPLES.

	I.	II.	III.	IV.	V.
$FeCO_3$	57·71	59·94	62·12	51·50	65·20
Fe_2O_3	10·86	6·45	1·36	1·83	0·32
$CaCO_3$ } $MgCO_3$ }	7·64	12·79	15·22	24·93	16·53
'Indifferent constituents'	23·79	20·82	21·30	21·74	17·95

From this table we can now 'reconstruct,' as it were, the original rock from which the various samples have been derived by weathering. To do this, it is only necessary to replace the ferric oxide by its equivalent of ferrous carbonate, and express the composition of the 'reconstructed' rock in percentages. Thus we get the following table, showing the composition of the 'reconstructed' rocks:—

	I.	II.	III.	IV.	V.
$FeCO_3$	70·00	67·36	63·73	53·74	65·57
$CaCO_3$ } $MgCO_3$ }	7·30	12·43	15·13	24·74	16·51
'Indifferent constituents'	22·70	20·21	21·14	21·52	17·92

Now, it will be noted that the amount of the 'indifferent constituents' is approximately constant in the five samples, and that the percentages of calcium- and magnesium-carbonates vary inversely as those of the ferrous carbonate. The reconstructed rocks, therefore, differ almost solely, owing to the greater or less replacement of ferrous carbonate by the fossil-making carbonates of calcium and magnesium. Thus, the chemical evidence points to the fact that the Mussel-Band and the pebbles are derived from the same source: the observed differences in composition being due, firstly, to the varying amounts of calcium- and magnesium-carbonates (the result of the irregular distribution of the fossil shells); and, secondly, to the degree of oxidation by weathering which the various samples have undergone.

The appended diagram (fig. 13, p. 545), in which the ordinates represent the composition of the 'reconstructed' rocks, while the samples are numbered off at convenient lengths on the abscissæ, exhibits clearly the relationships just described.

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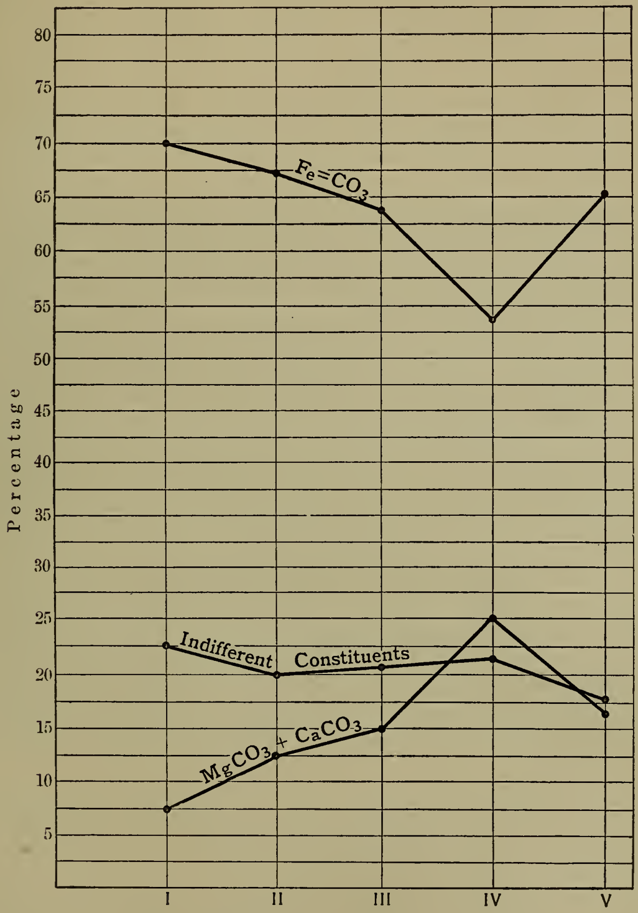
[1] R. Brauns, 'Chemische Mineralogie' 1896, p. 354.

Fig. 13.—*Diagram exhibiting the relationship in composition between the weathered and the unweathered rocks.*



At the very base, the Table-Rocks Sandstone is extremely hard and compact, and its under-surface, which rests upon the eroded shales, is marked by peculiar knobs and sinuous ridges. This hard rock passes rapidly upwards into the ordinary softer massive sandstone, which when weathered shows concretionary structure on a large scale, the oval segregation-patches being much redder than the surrounding rock. Chemical analysis shows a concentration of iron and phosphorus in the rock immediately overlying the shales of the Lower Series, thus :—

Analysis (1) of samples from the actual base, and (2) of samples from about 6 feet above the base.

	(1)	(2)
FeO ……………………	trace	none
Fe_2O_3 ……………………	1·43 °/₀	0·91 °/₀
P_2O_5 ……………………	0·07 °/₀	none.

IV. Conclusions.

From the various facts recited in the foregoing pages, it seems inevitable to conclude that: (1) the beds to which we have referred as the Lower Series suffered a considerable amount of denudation before the Upper Series or Table-Rocks Sandstone was deposited, and that this denuded surface occupied a large area; (2) that after the deposition and consolidation of the Upper Series, a movement took place which thrust that series northwards over the shales and other beds of the Lower Series.

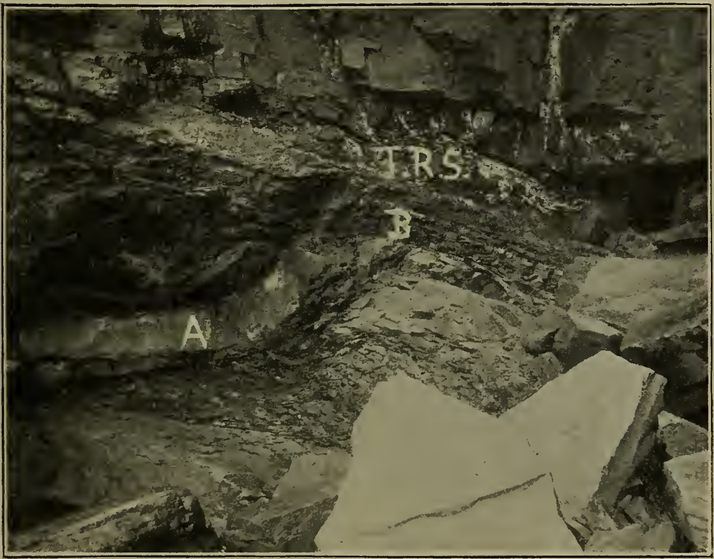
The actual amount of denudation, and the consequent time-value of the unconformity, we have as yet no means of appraising. The actual amount of horizontal displacement or overthrusting we have also, unfortunately, no means of gauging. It seems clear, however, that most, if not all, of the small faults, sharp folds, and other disturbances affecting the Lower Series of beds, are the result of the moving of the Upper Series over them, generally speaking along the pre-existing plane of denudation.

In this case, then, we may regard the thrust as one in which a massive and compact set of rocks was dragged or pushed over a previously-prepared floor chiefly composed of soft, clayey, and, so-to-speak, specially-lubricated material, the nature of the rocks above and below the unconformity providing the required line of least resistance. Where the lubrication was least perfect accidents happened. Thus at F a tongue of Upper Sandstone pierces the shale beneath (see fig. 6, p. 536). At E, the sandstone has been pressed against the hard Mussel-Band and reared up into a fine curl (fig. 14, p. 547).

At several spots the sandstone has ploughed into the shales, hardening and sometimes slickensiding them, as for example on the beach at C, where high-dipping sandstone can be seen resting upon slickensided shale.

The action referred to seems intimately connected with the production of the stony ridges, which have been mentioned as occurring at J, K, and M, and deserve special notice. These ridges consist essentially of outcrops of sandstone belonging to the basement-portion of the Table-Rocks Sandstone, but striking from the base of the cliff, and transversely to it, for some 8 to 10 yards, and intruded dip-wards into the shales of the Lower Series for a distance of 4 to 8 feet. At first sight, these downward-torn apophyses of the Upper Sandstone present the appearance of dykes, but a careful study of the circumstances leaves little doubt as to their real nature. A few simple diagrams will sufficiently illustrate our explanation (see fig. 15, p. 548). The first of these figures (*a*) shows the mode of occurrence of these ridges in plan. It will be noted that the outcrop of sandstone (of the Lower Series) marked × is entirely unaffected by the ridges, or by the disturbance occasioned by them. The second figure (*b*) shows the actual section parallel to the cliff-line (and parallel also to the general strike of the Table-Rocks Sandstone) and about 3 yards from it. The third figure (*c*) is one parallel to the last, but representing the probable state of things beneath the cliff. Figures (*d*) and (*e*) show sections at right angles to the cliff-line, one where there is no intruding ridge, and the other along the line of such a ridge. The presence of pebbles in one of the sandstone-ridges at M affords a further confirmation of our interpretation.

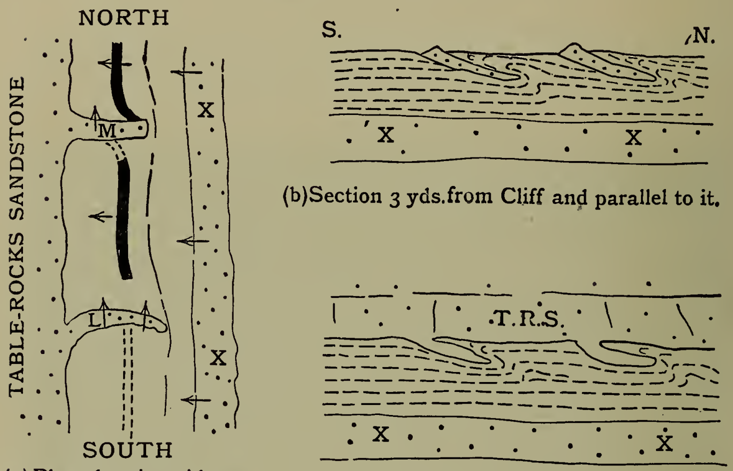
Fig. 14.—*(See fig. 4, p. 535, northern end of the section.) Photograph showing the lowest bed of the Table-Rocks Sandstone (A) curled up and abutting against the Mussel-Band (B).*



The thrusting action is most marked at the junction of the hard and soft beds, that is along the plane of the unconformity. Thus the sandstone-'curl' at E contains pebbles; at F two distinct beds of pebbly sandstone are separated by what is probably squeezed-in, or intruded shale (see fig. 6, p. 536); and at G a mass of conglomerate, containing pebbles derived from the Mussel-Band, has been forced under the Mussel-Band itself (see fig. 8, p. 538).

In the section from M to N, the pebble-bed has been torn to shreds, and is mixed up with pieces of shale and sandstone, oriented at every conceivable angle. Here too, as has already been pointed out, the movement has extended several feet above the unconformity, as is shown by the presence of small faults bounded by clay-partings. Where these faults occur, the rock-material is often indescribably shattered and mixed. Where the thrusting coincides least with the unconformity, there the moving mass was least resistant, or in other words most shaly.

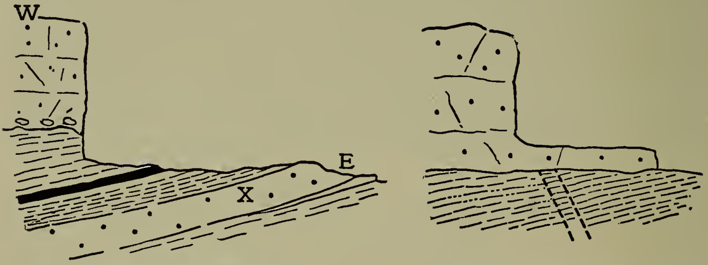
Fig. 15.—*(See p. 547.)*



(a) Plan showing ridges.

(b) Section 3 yds. from Cliff and parallel to it.

(c) Section parallel to last, but beneath the Cliff



(d) Section across the Cliff where there are no ridges

(e) Section across the Cliff where there is a ridge (at K)

As further evidence of the thrust, it may be added that the master-joints of the Upper Series are never continued in the Lower.

Another point worth noting is that the more marked prominences of surface of the Lower Series are invariably those which bear the strongest marks of disturbance.

As regards the evidence for the direction followed by the thrusting movement, the chief points have already been mentioned. To these it may be added that the direction of the minor thrusts in the Upper Series (see Pl. XLII) is clearly from south to north; that the small faults transverse to the general line of section are east-and-west faults; and generally that the orientation of disturbed shale-fragments, the motion of which has been arrested by harder beds, also indicates movement from the south (see fig. 16, above).

Fig. 16.—*Photograph showing the direction of the thrust. A=shale, wedged from south to north into the underlying sandstone (B).*

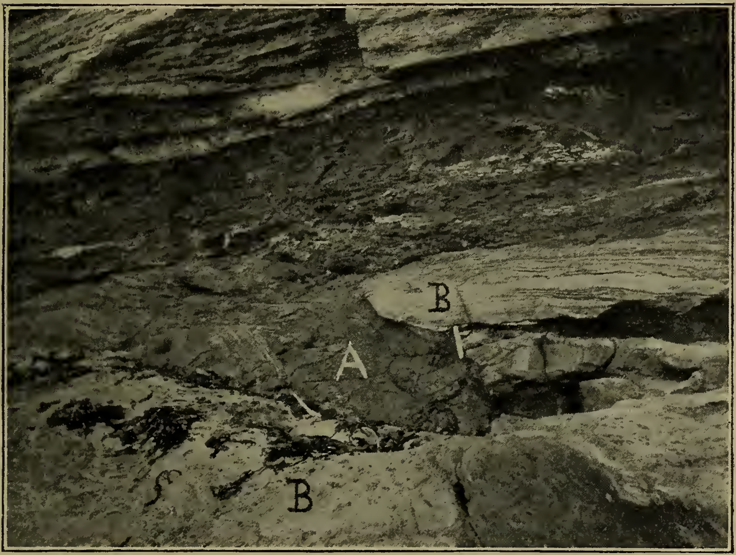
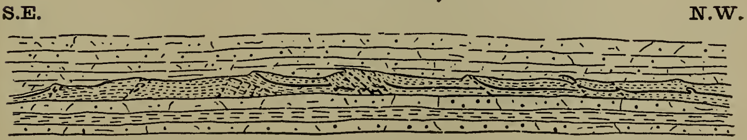


Fig. 17.—*General section from A to N.*



The action of the thrust is markedly rhythmical, short stretches of highly-disturbed beds alternating with others in which the dip is gentle (see the general section, fig. 17). With the latter disposition, there is often no noticeable discordance of dip between the two Series, and the pebbles form in such cases about the only means of detecting the unconformity. The stormy episodes are generally marked by the elevation above the general level of the eroded surface of the lower shales. Thus, to some extent, the thrust masks the unconformity, since the wavy uneven outline of the surface of the Lower Series is partly the result of the disturbances caused by the thrust; and, furthermore, violent discordance of dip between the upper and the lower beds, in so far as produced by thrusting, is no criterion of the unconformity.

EXPLANATION OF PLATE XLII.

Section from M to N (see the sketch-map, fig. 1, p. 532), on the scale of about 18 feet to the inch, vertical and horizontal.

Discussion.

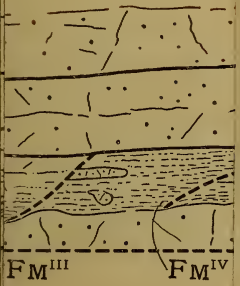
The Chairman (Mr. R. S. Herries) said that the paper once more showed the value of a series of observations conducted over a long period in a particular district.

Mr. Lamplugh complimented the Authors on their clear exposition of this striking example of disruption between 'strong' and 'weak' beds. He was reminded of analogous phenomena in another East-Coast section, on the north side of Flamborough Head, where the massive flinty Chalk had been locally thrust over the more thinly-bedded Lower Chalk. He would ask the Authors whether they had considered the possibility that the supposed pebbles might be due to the breaking-up of the lower beds during the movement.

Mr. Fox Strangways said that the previous speaker had referred to the thrust-plane which occurs at the junction of the flinty Chalk with the non-flinty Chalk in the cliffs of Flamborough Head. As he (the speaker) knew this section very well, he was happy to endorse Mr. Lamplugh's remarks, and to state that the rocks at the foot of Buckton Cliffs appeared to have been subjected to very much the same conditions as those mentioned by the Authors at the base of the Table-Rocks Sandstone; also that the peculiarities noted by them were, no doubt, due to the thrusting of this rock over the beds below.

Prof. Watts pointed out that the paper was of considerable interest, because it showed the result of years of denudation on the thrust-plane, which was a common phenomenon at the junction of strong and weak rocks. The Authors seemed to have established the fact of unconformity, and that thrust was insufficient to explain the whole of the phenomena.

Mr. R. H. Tiddeman, without offering an opinion on the suggested unconformity, said that frequently, where Carboniferous sandstone rested on clay or shale, the upper bed contained pebbles of the lower; but such erosion did not necessarily imply any considerable unconformity.


FM^{III}
FM^{IV}

Section from M to N (see sketch-map, fig. 1, p. 532). Length = about 100 yards. The black patches are 'scares' of coal.